INTRODUCING SUSTAINABILITY IN COLLEGE CALCULUS

by

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Abstract

As the effects of climate change make themselves more apparent with each passing year, it becomes essential to get minds of disciplines across the board involved with the discussion on where human action needs to go from here to address the issues a changing global environment presents. Classrooms of all levels provide the ideal place to begin having the discussion about sustainable living with future decision-makers. Furthermore, mathematics courses provide the perfect opportunity to strengthen the critical thinking and analytical skills needed to approach sustainability issues. This paper summarizes one of the first documented attempts to bring the topic of sustainability into mathematics courses through the introduction of sustainability-related calculus problems and statistically analyzes differences in student perception across the semester.

Acknowledgements

Thank you to my (super)mom for raising me to believe in myself. Thank you to my dad who let me run around barefoot in the woods. Thank you to all of my math teachers over the years for teaching me the joy hidden in numbers.

Contents

1 Introduction

According to the Environmental Protection Agency, climate change refers to "any significant change in the measures of climate lasting for an extended period of time," including "major changes in temperature, precipitation, or wind patterns, among other effects, that occur over several decades or longer" (EPA, 2017). At this point, scientists largely agree that climate change is occurring and is due to human activity. Currently, the earth's average temperature has risen by 1.5°F over the past century, a change that has been met with changes in rainfall, more floods, droughts, and intense rain, more frequent and severe heat waves, melting ice caps, and rise in ocean level and acidity (EPA, 2017).

As hundreds of societies across the world begin to face the effects of global climate change, it becomes essential that the general public be informed about and engaged with the issue of climate change. As it stands, not many people are talking about climate change. In a study conducted by Yale and George Mason University's programs for Climate Change Communication in the fall of 2015, only 35% of Americans responded that they "discuss global warming with family and friends at least occasionally" (Yale, 2015). The importance of the general public discussing climate change in a scientifically correct manner cannot be overstated. Public understanding of climate change and connections of its influence to what people find meaningful or valuable are socially constructed, "with interpersonal disucssions serving as one of the most dominant means by which this construction occurs" (Swim et al., 2014). As such, it is paramount that as much of the public as possible enter the conversation with a foundational understanding of the risks of climate change as to effectively push discourse towards "the development of laws and policies" favoring a more sustainable future (Swim et al., 2014). Classrooms in public and higher education provide the ideal place to build upon students' foundational understanding of climate change in an educational setting, and mathematics courses have the capability to strengthen students' analytical understanding of public issues.

Many non-mathematically driven students fail to see the crossover between mathematical comprehension and the humanistic or social issues in which they might hold more interest. Meanwhile, students in STEM (Science, Technology, Engineering, and Mathematics) related disciplines understand the importance of quantification in their own field but "rarely see the humanistic and social aspects of their work" (Baird et al. 2017). For both of these sets of students, the ability to quantify "real-world" topics becomes the key to building a bridge between the technical and humanistic views. While non-STEM students can become more engaged with learning mathematics by using it as a tool to explore their own interests, STEM students begin at the other side of the bridge by grounding technical applications in the "social, ethical, and political issues" of our time (Baird et al. 2017). One of the most useful beginnings to bridge this gap between the humanities and the sciences is the discussion of sustainability, a topic that falls almost neatly in the middle of the divide.

Finding common ground between mathematics and more social fields also invites the possibility of a more genuine mathematics education. Many students groan about taking mathematics courses as they must memorize formulas and set ways of approaching particular types of problems, never understanding the connection between mathematics and their own lives. Students often assume that there is one correct answer hidden somewhere in the teacher's answer key, and math class becomes more focused on "acquiring certain competencies" than on using math as a tool to explore the unknown (Renert 2011). Climate change, like many big picture issues, has no set answers and thus requires creative approaches to problem-solving. By introducing sustainability in mathematics courses as many branches of problems with no set answers, the responsibility of knowledge is shifted from the professor to the students, allowing students to think and analyze critically and creatively and possibly to bring about action in their own communities based on their findings (Renert 2011). In our project, we were unable to provide open-ended sustainability questions for the students to develop their own creative approaches towards answering, as all of our problems had "set answers" for the students to calculate. We hope to get more educators on board with creating sustainability-related math questions so that in the future, math courses will see more discussion-based (rather than purely computational) questions related to sustainability issues.

As it stands, no existing research "directly addresses how mathematics teaching might contribute to climate change education" (Barwell, 2013). This paper describes a first attempt at introducing sustainability to students of all majors in a Calculus I course and discusses the results of the experience through an analysis of surveys given to the students. For a comprehensive description of the process and survey results, as well as the full text of all problems introduced throughout the semester, please visit `https://miloshsr1.wixsite.com/calculus`.

2 Goals of the Project

The main goal of this project was to involve students with sustainability who might never have stepped into a sustainability course. We aimed to combine mathematics and sustainability in an interesting and captivating way so students would recognize the link between the two fields and acknowledge the importance of each. By critically examining and interpreting calculus problems that involved certain sustainability topics, we hoped that students would gain strength in analytically approaching the sustainability issues of our time.

On top of the main goals, however, we were simply curious if students would enjoy real-life applications in their math courses more so than examples to which they are unable to connect to their lives as easily. We hoped to see that students were more fascinated and involved with the course after seeing the mathematics they were learning applied to things they see in every day life.

3 Describing the Process

Before the semester began, Dr. Palmer and I created a pre-semester survey based on what we thought might come of the semester. Certain questions covered student perception of and actions involving sustainability topics we planned to cover during the semester, while others were more general questions we hoped we would be able to ask again at the end of the semester to mark any change. During the semester, we developed problems topic by topic about a week before the professors would introduce them to the class. This process involved a lot of data mining and creative thinking about how to model certain processes. After we solidified a problem for that week's topic, I would branch off and research the sustainability topics covered in the problem in order to pair an optional discussion with the problem. We asked professors to keep track of whether or not they included the sustainability question, where it was included (homework, quiz, etc), and whether or not they paired the discussion with the question. Towards the end of the semester, we created questions for our post-semester survey now knowing the topics we had covered and what we would like to analyze about the experience. We attempted to pair as many questions as possible to the pre-semester survey in order to analyze change in student answers, and the rest of the questions on the survey were about the experience as a whole and what students took away from it.

3.1 The Difficulties

I went into the semester thinking that constructing calculus problems was going to be a breeze. What I failed to account for is that real life data does not fit nicely into smooth functions. We began the semester by trying to force data into each week's calculus topics. Once our luck ran out with finding simple, smooth curves about which we could ask the simple introductory calculus questions, we revised our approach and held meetings just to brainstorm processes that might be modeled by different types of functions. Once we had an idea in mind, we split apart to search for data by which we could create a function. Searching for the data alone could often take a few hours, and occasionally, once we had the data and were manipulating it to create a function, we would have to abandon the data because it did not fit our needs for that week. Another difficulty we kept running into was wording of these problems. It is easy enough to think that something you wrote makes sense, but while revising questions before we sent them out to the professors, we were often stumped on how best to word what we were trying to ask. Because of this whole experience, I doubt I will ever take a textbook for granted again.

4 Analyzing Surveys

We implemented two surveys; one at the beginning and one at the end of the semester. Both surveys were optional, anonymous, and conducted through Qualtrics, an online survey software (Qualtrics, 2015). 82 students fully completed the pre-semester survey, and 99 students fully completed the post-semester survey.

Since we created the pre-semester survey without fully knowing which sustainability topics we would touch on during the semester, we abandoned a few of the questions involving topics we never discussed in our problems. The rest of the questions on the pre-semester survey were general enough that we were able to ask the same questions almost verbatim on the post-semester survey. Each of these eight paired questions involved a ranking of statements on a seven-point Likert Scale (Strongly Disagree, Disagree, Somewhat Disagree, Neutral, etc...). Since the questions on the pre-semester survey and the post-semester survey were worded closely enough, we approached their analysis through a Chi-Square Test of Homogeneity, a test that analyzes whether two populations have the same proportion of observations. In this case, the two populations would be the two surveys, and the proportions would be the proportion of students who chose each level of the Likert Scale.

Chi-Square Tests are used when three conditions have been met: (1) The sample was selected through simple random sampling. (2) The variable under study is categorical. (3) If the data is displayed in a contingency table, the expected frequency count for each cell is at least 5. Unfortunately, we failed the third condition and were so unable to use the Chi-Square Test of Homogeneity. However, we ran a Monte Carlo simulation instead, which is essentially the exact same test as Chi-Square Test of Homogeneity but is used when Chi-Square conditions have failed and uses computer simulations and probability distributions to come up with a p-value. The null hypothesis of the Monte Carlo simulation is that the distribution of observations among the two populations is the same. In our case, if we obtained a statistically significant p-value, we could reject the null hypothesis and claim that the distribution of student answers between the two surveys is different. There is no post-hoc test to analyze where that difference lies; rather, we have to examine visually the difference in distribution for those two populations. For each of these eight questions, I ran a Monte Carlo simulation to test for significance of difference and then followed up by examining bar charts of the percentage of students under each Likert category for the two surveys.

It was sometimes difficult to see exactly where the change was occurring while examining bar charts of the seven-point Likert scale, as oftentimes, an increase in students answering "Strongly Agree" would be compensated for by a decrease in students answering "Agree." To simplify the visual analysis of a shift in student answers, I included bar charts of student answers among the combined Likert Scale, a scale that now involves only "Disagree," "Neutral," and "Agree." To get the percentages of students among this combined Likert Scale, I simply combined (summarized) the percentages of students who answered "Strongly Disagree," "Disagree," and "Somewhat Disagree" into the combined "Disagree" category, and likewise for "Agree." Students who answered "Neutral" stayed as such.

An analysis of each of these eight paired questions is detailed in the sections below. The first section consists of statistically significant results, and the second consists of non-statistically significant results. While we want to focus on those questions that had a significant change in difference, I felt it important to include an analysis of all eight questions, as the results are oftentimes interesting to explore further. The wording for each question on the pre-semester and post-semester surveys, respectively, are included at the beginning of each analysis.

4.1 Statistically Significant Results

The following questions saw a statistically significant change in distribution of student answers over the course of the semester:

"Rate the following statements to the best of your ability..."

4.1.1 Question One: Student Satisfaction

"I have been satisfied with the math courses I have taken previously."

"I have been satisfied with this math course."

The counts for Question One on both surveys can be found in Figure 1. The frequency tables for each of these questions can be a bit misleading, as only 82 students completed the pre-semeser survey as compared to the 99 who completed the post-semester survey, so a jump in count might not necessarily mean a jump in proportion. However, the Monte Carlo simulation tests for difference in distribution (proportion) of student answers using this table, so I have included a table for each of the questions. What will be more telling is the p-value that comes with the Monte Carlo simulation for each question, followed by a visual analysis of the percentage of students under each category of the Likert Scale. This visual analysis will be based on bar graphs included.

	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Before	3	4	3	10	18	36	8
After	3	0	5	6	12	36	37

Figure 1: Counts for Question One

Running a Monte Carlo simulation on the frequency table yielded a p-value of 0.0009. Thus we can conclude with extreme confidence that there is a difference in the distribution of student answers on this question between the pre-semester and the post-semester survey. That is, there has been some change in student satisfaction of math courses over the semester. To further examine that change, we will look at a visual representation of the percentage of students under each category for the two surveys. The bar chart of percentages can be found in Figure 2.

Note that the percentage of students answering this question who strongly agreed that they were satisfied with this course is more than 25% higher on the post-semester survey than it was on the pre-

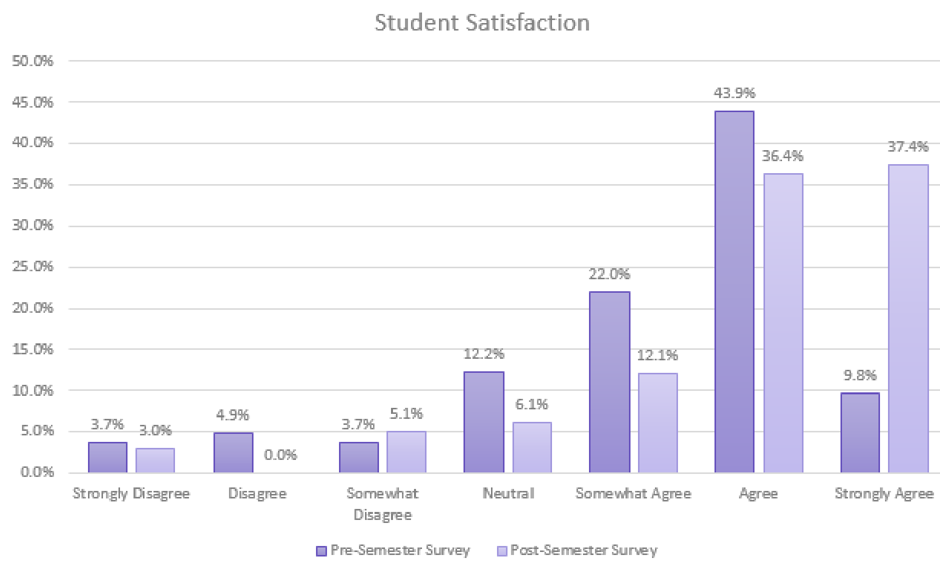

Figure 2: Percentage of Students in Each Category for Question One

semester survey. As mentioned earlier, this large increase in the percentage of students strongly agreeing with the statement has been compensated for by a drop in the percentage of students falling under the other "agree" categories. To more easily see the change in general agreement, neutrality, or general disagreement, I have included a second, combined bar chart of percentages in Figure 3.

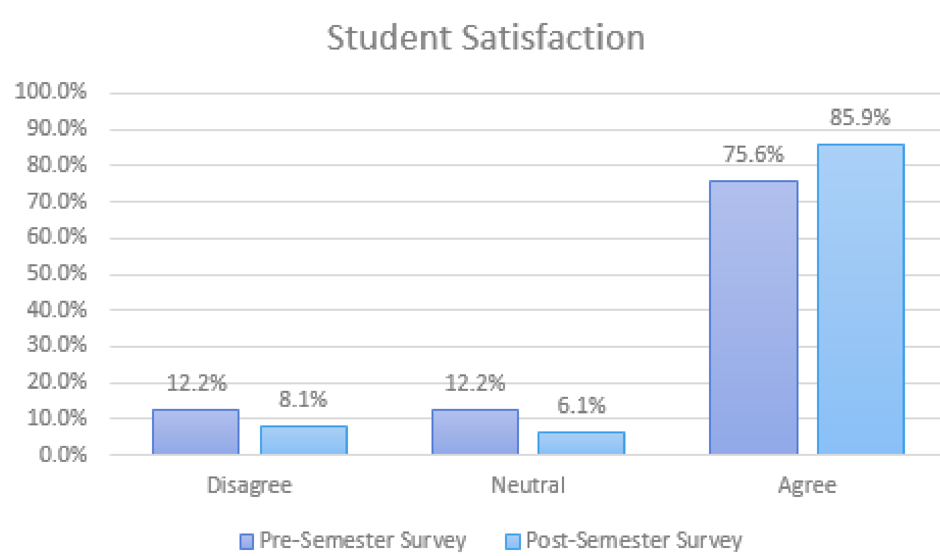

Figure 3: Percentage of Students in Combined Categories for Question One

It is much easier to see now that there is about a 10% increase in the percentage of students who agree to some extent that they were satisfied with this course as compared to the percentage of students who were satisfied with previous math courses. Note that our observational study does not allow us to claim that our problems caused this change in satisfaction. It very well could have been that the professors teaching the course were strong educators, and the students felt more satisfied in the course because of the improved quality of teaching over previous math courses.

4.1.2 Question Two: Student Success

"I have been successful in my previous math courses."

"I was successful in this math course.

The counts of student responses for both surveys can be seen in Figure 4.

	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Before	2	3	5	5	20	33	14
After	5	9	7	10	27	19	22

Figure 4: Counts for Question Two

Running a Monte Carlo simulation on this table yielded a p-value of 0.08346. Thus, we can conclude at the 90% confidence level that there is a difference in the distribution of student answers for this question between surveys. That is, there has been some change in student answers of whether or not they were successful in this course as compared to previous math courses. To examine that change further, refer to Figure 5.

Note that this graph is not very telling; the only percentage that went down is the percentage of students who agreed, while the percentage of students in all other categories increased. We will have to combine the Likert Scale to get a clearer picture of what sort of change is actually occurring here. Refer to Figure 6.

It is much easier to see now that the percentage of students who agreed to some extent that they were successful in this course as compared to previous courses has decreased over the course of the semester by 13%. The percent of students taking these surveys who disagreed that they were successful in this course has increased by about 10%. It is interesting here that while a higher percentage of students disagreed that they were successful in this course, a higher percentage of students agreed that they were satisfied with this course. This hints that while this course was more challenging for students

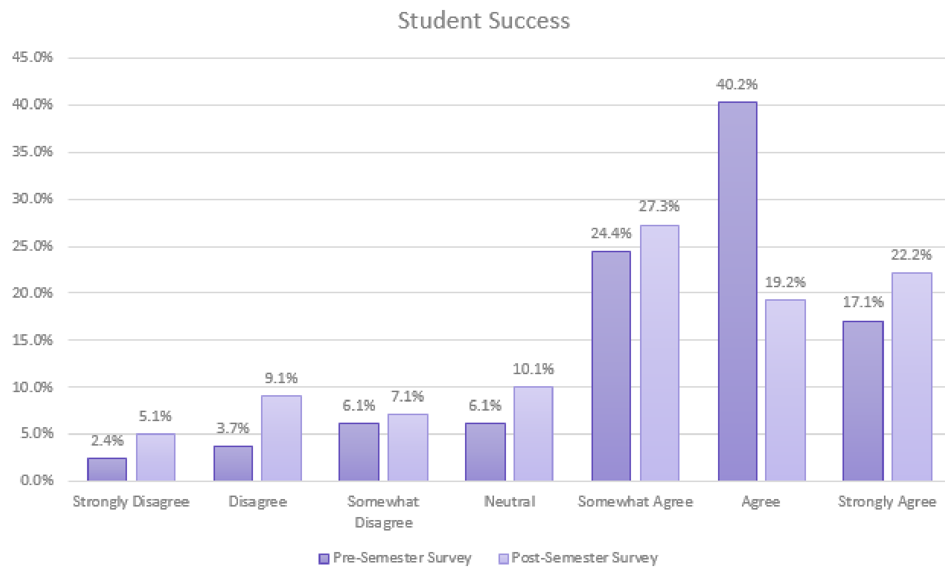

Figure 5: Percentage of Students in Each Category for Question Two

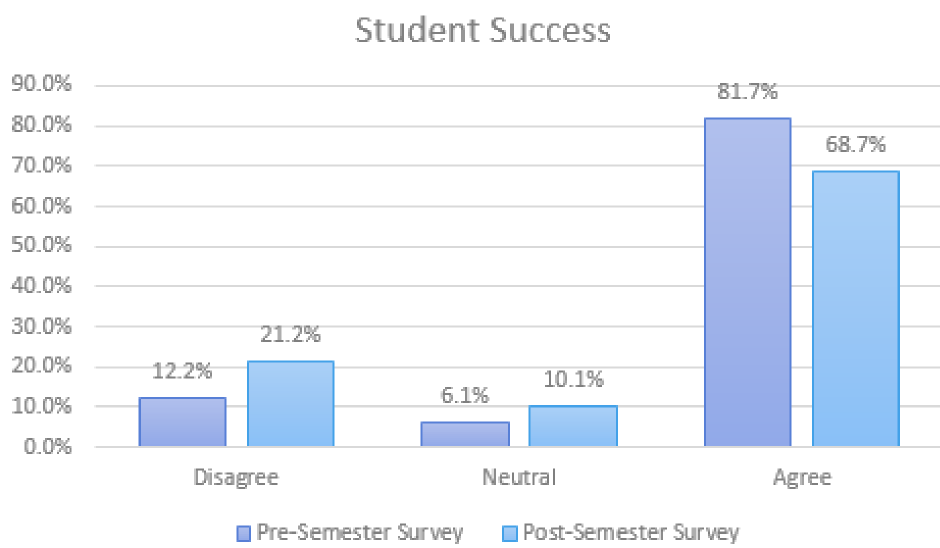

Figure 6: Percentage of Students in Combined Categories for Question Two

than previous math courses, they were able to get more satisfaction out of the course than they had in previous math courses.

4.1.3 Question Three: Math Through Real-Life Examples

"Math has been explained to me through real-life examples."

"Math has been explained to me through real-life examples."

The counts of student responses for both surveys can be seen in Figure 7.

	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Before	1	4	7	8	27	26	9
After	2	1	2	5	19	41	29

Figure 7: Counts for Question Three

Running a Monte Carlo Simulation on this question yielded a p-value of 0.002999, so we can reject the null hypothesis that the distribution of students among the Likert Scale is the same for both surveys and conclude that the proportion of students in at least one of the categories has changed over the course of the semester. To examine this change further, Figure 8 shows the percentage of students in each category on both surveys.

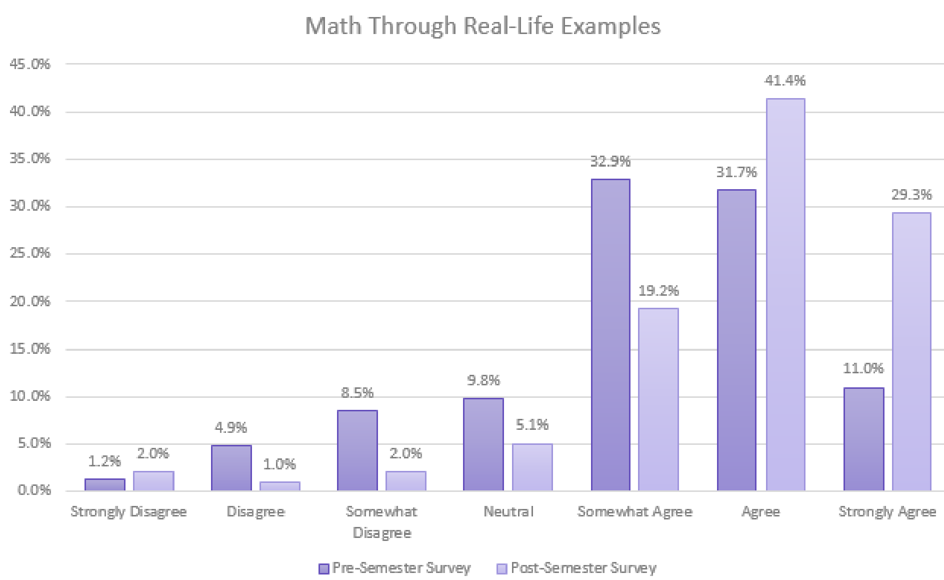

Figure 8: Percentage of Students in Each Category for Question Three

It can be seen that a much larger percentage of students answered "agree" or "strongly agree" on the post-semester survey than on the pre-semester survey. Just to be sure that this is the predominant change occurring, a bar chart of percentages among the combined Likert Scale can be found in Figure 9. Note that there is an increase of almost 15% of students who agree with the statement that math has been shown to them through real-life examples. We wonder whether the increase in students agreeing that math has been shown to them through real-life examples has anything to do with the increase in

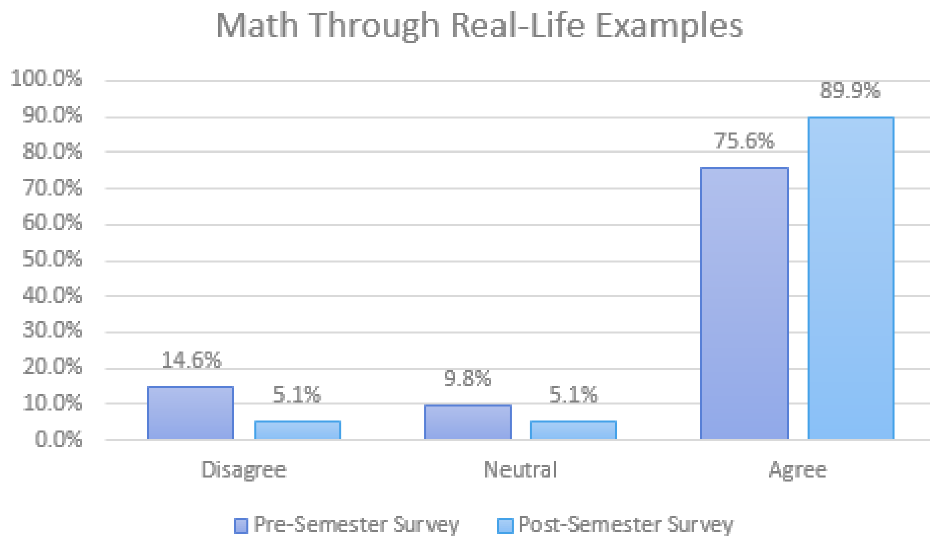

Figure 9: Percentage of Students in Combined Categories for Question Three

student satisfaction of the course.

4.1.4 Question Six: Recognizing the Association Between Math and Sustainability

"Math is associated with sustainability."

"Math is associated with sustainability."

The counts of student responses for both surveys can be seen in Figure 10.

	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Before	0	2	8	12	8	34	18
After	1	2	1	8	20	41	26

Figure 10: Counts for Question Six

Running a Monte Carlo Simulation on this question yielded a p-value of 0.03448, so we can confidently reject the null hypothesis and conclude that there the proportion of students in at least one of the Likert Scale categories has changed over the course of the semester. To examine this change further, Figure 11 shows the percentage of students in each category on both surveys. It can be seen that a larger percentage of students fall under the varying "agree" categories on the post-semester survey than on the pre-semester survey. To see this change a bit more clearly, refer to Figure 12. Note that there is almost a 15% increase in the percentage of students who agree to some extent that math is associated with sustainability. This is one of our more exciting survey results, as it shows students making the connection between math and sustainability over the course of only one semester.

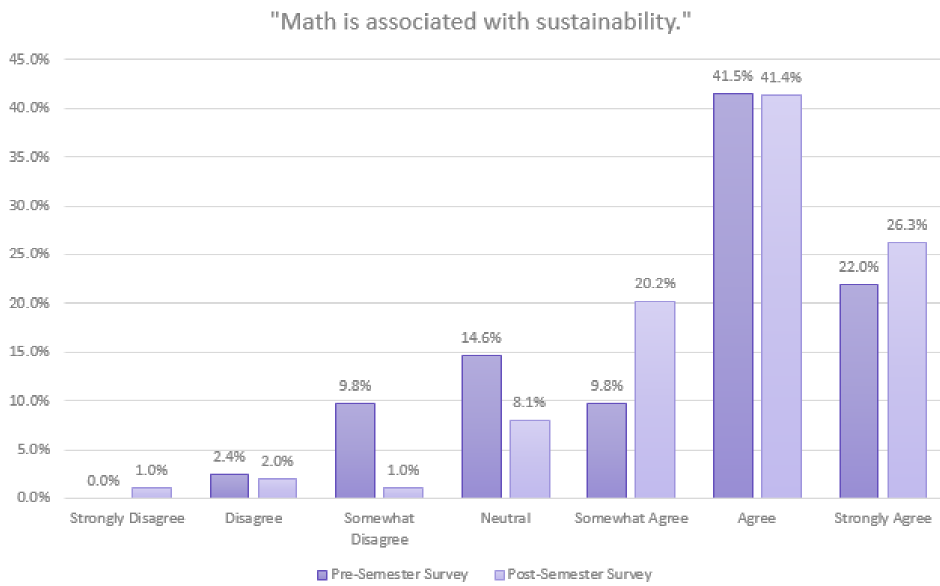

Figure 11: Percentage of Students in Each Category for Question Six

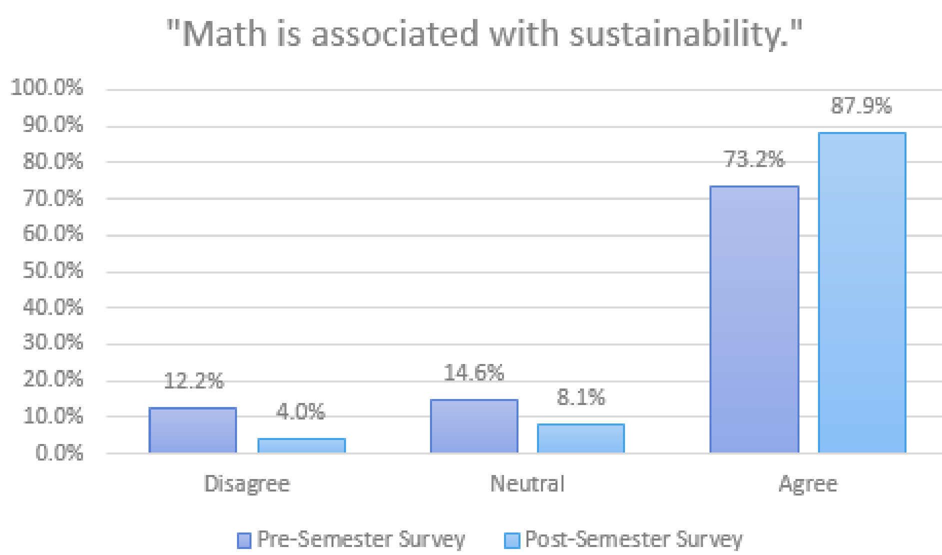

Figure 12: Percentage of Students in Combined Categories for Question Six

4.1.5 Question Seven: Student Understanding of Sustainability

"I feel as though I fully understand what 'sustainable living' means."

"I feel as though I fully understand what 'sustainable living' means."

The counts of student responses for both surveys can be seen in Figure 13.

	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Before	1	3	6	6	25	32	9
After	0	2	1	10	24	40	21

Figure 13: Counts for Question Seven

Running a Monte Carlo simulation on the table yielded a p-value of 0.096. Thus we can reject the null hypothesis at the 90% confidence level and conclude that there has been a change in the distribution of student answers over the course of the semester. To further examine that change, refer to Figures 14 and 15 for the bar charts of the Likert Scale and combined Likert Scale responses.

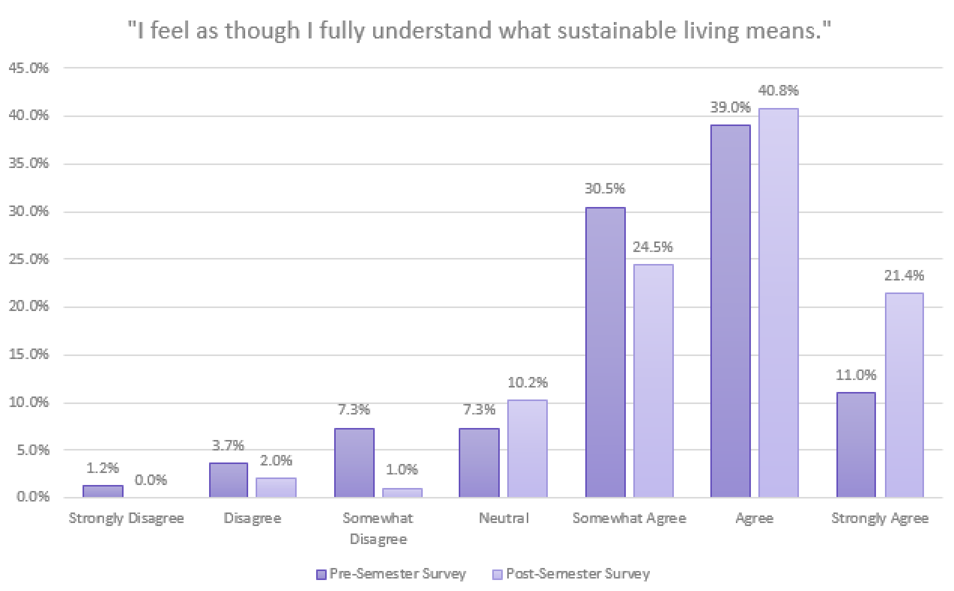

Figure 14: Percentage of Students in Each Category for Question Seven

Note that, looking at the combined graph, we see about a 15% increase in the percentage of students who agree to some extent that they understand what living sustainably means. It is exciting that only one semester at Appalachian State allowed this set of students to feel a bit more comfortable in their understanding of sustainable living.

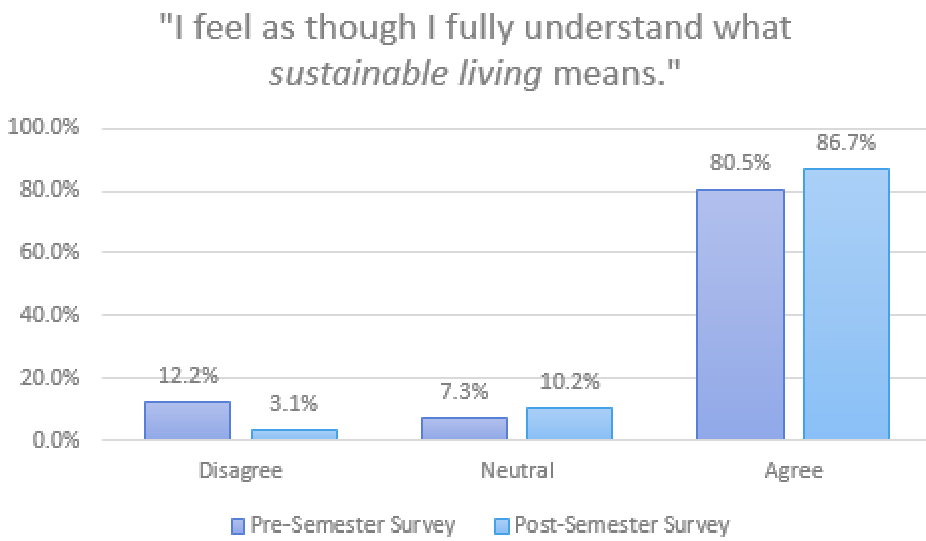

Figure 15: Percentage of Students in Combined Categories for Question Seven

4.2 Non-Statistically Signifcant

We did not see a statistically significant difference in the distribution of students between surveys for the following questions:

"Rate the following statements to the best of your ability..."

4.2.1 Question Four: Math Seen as Useful

" I feel as though the math I am learning is useful."

"I feel as though the math I learned this semester was useful."

The counts of student responses for both surveys can be seen in Figure 16.

	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Before	3	3	6	9	20	25	16
After	3	5	3	6	18	35	29

Figure 16: Counts for Question Four

Running a Monte Carlo simulation on this table yielded a p-value of 0.4148, a value too large to be statistically significant. Although we cannot claim a significant change in the distribution of student answers over the course of the semester, it is worthwhile to examine visually the differences in student answers. Figure 17 and Figure 18 show the bar charts for percentage of student answers among the

Likert Scale and combined Likert Scale, respectively.

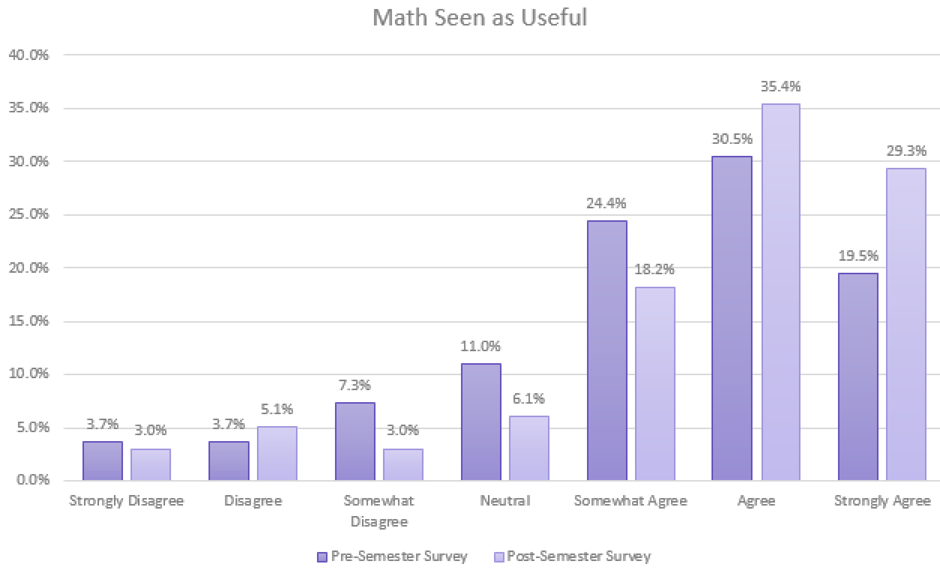

Figure 17: Percentage of Students in Each Category for Question Four

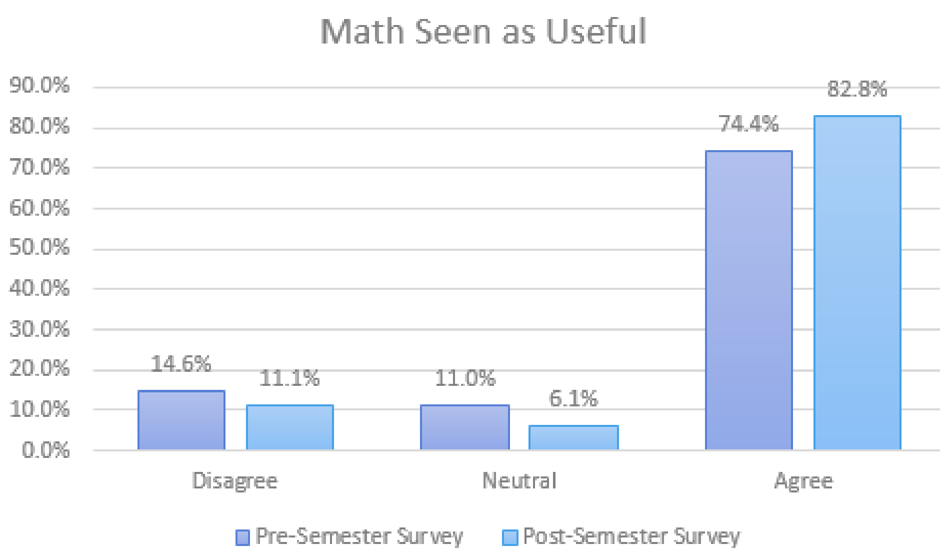

Figure 18: Percentage of Students in Combined Categories for Question Four

Note that we see an increase in the percentage of students strongly agreeing and agreeing that math is useful, and looking at the combined scale shows that there is a little under a 10% increase in the percentage of students who agree that math is useful after the semester is over. Although this change is not statistically significant, it is an exciting change to see, particularly knowing that over 80% of students surveyed at the end of the semester agree to some extent that the math they learned in calculus was useful!

4.2.2 Question Five: Student Commitment to Sustainability

"Living sustainably is something I care about."

"Living sustainably is something I care about."

The counts of student responses for both surveys can be seen in Figure 19.

	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Before	1	2	1	5	13	28	31
After	0	1	5	4	9	38	42

Figure 19: Counts for Question Five

Running a Monte Carlo simulation on the table yielded a p-value of 0.4063. Thus, we cannot conclude with confidence that there has been a change in the distribution of student answers over the course of the semester. Still, let us examine visually the difference in student answers between surveys. Figure 20 shows the percentage of students under each Likert Scale category, while Figure 21 shows percentages of students under the combined categories.

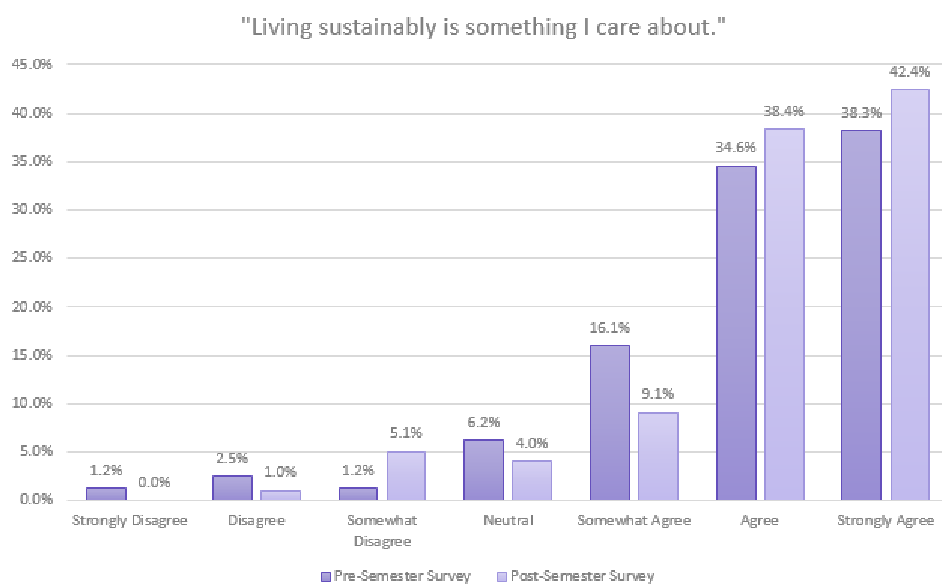

Figure 20: Percentage of Students in Each Category for Question Five

The second graph shows a bit more clearly why the change in student answers was not significant. We see the smallest hint of an increase in both the "agree" and "disagree" categories, but this is not

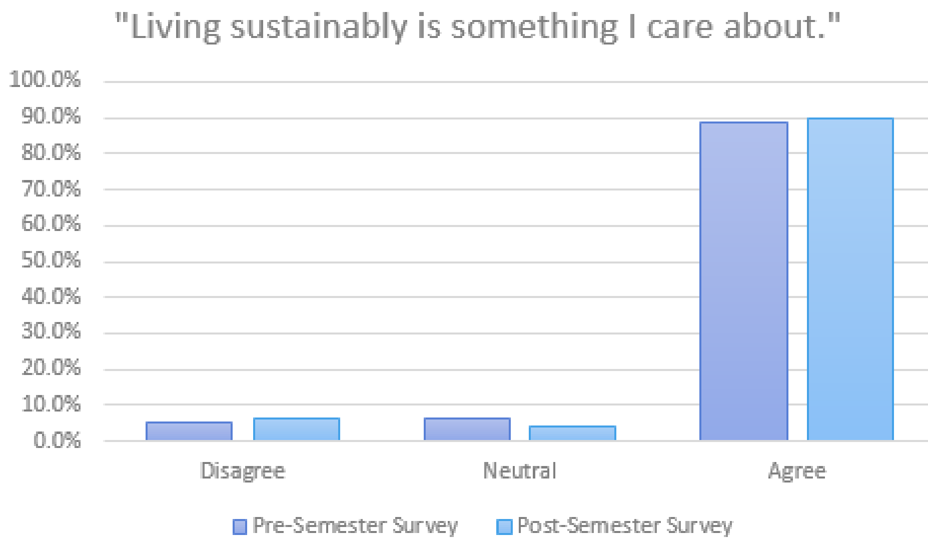

Figure 21: Percentage of Students in Combined Categories for Question Four

nearly enough to claim that the change in proportion between surveys was significant. However, note that on both surveys, roughly 90% of students agreed to some extent that living sustainably is something they care about. This is a statistic of which Appalachian State can be proud.

4.2.3 Question Eight: Perception of Where the United States Stands

"As a whole, the United States is living sustainably."

"As a whole, the United States is living sustainably."

The counts of student responses for both surveys can be seen in Figure 22.

	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Before	27	21	12	17	4	0	1
After	24	22	16	20	8	5	3

Figure 22: Counts for Question Eight

Running a Monte Carlo simulation on this table yielded a p-value of 0.3423. Thus, we cannot reject the null hypothesis that the distribution of student answers is the same across both surveys. However, the results of this question are interesting enough to take the time to examine the two sets of bar charts, both regular Likert Scale and combined Likert Scale, in Figure 23 and Figure 24, respectively.

Note that, looking at the combined Likert Scale graph, we see about a 10% shift from students

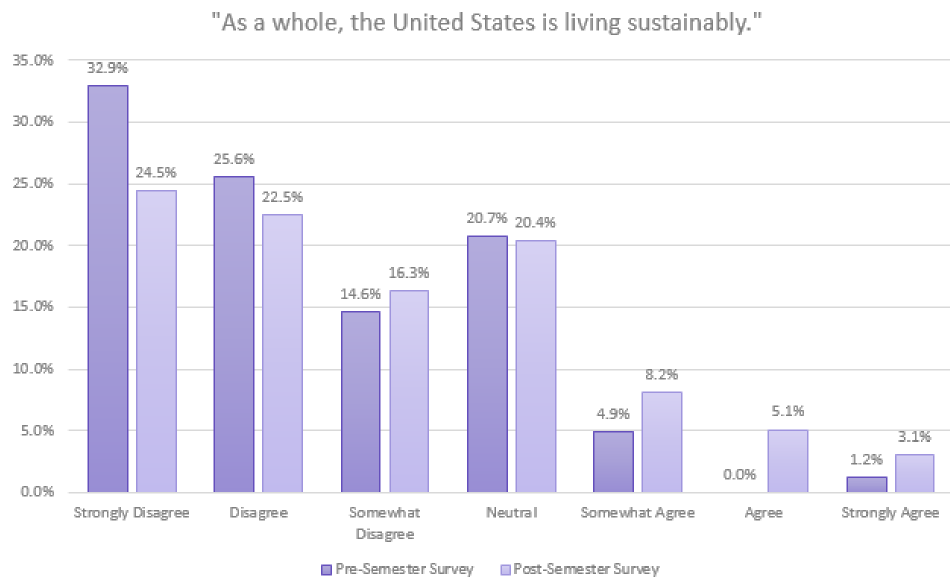

Figure 23: Percentage of Students in Each Category for Question Eight

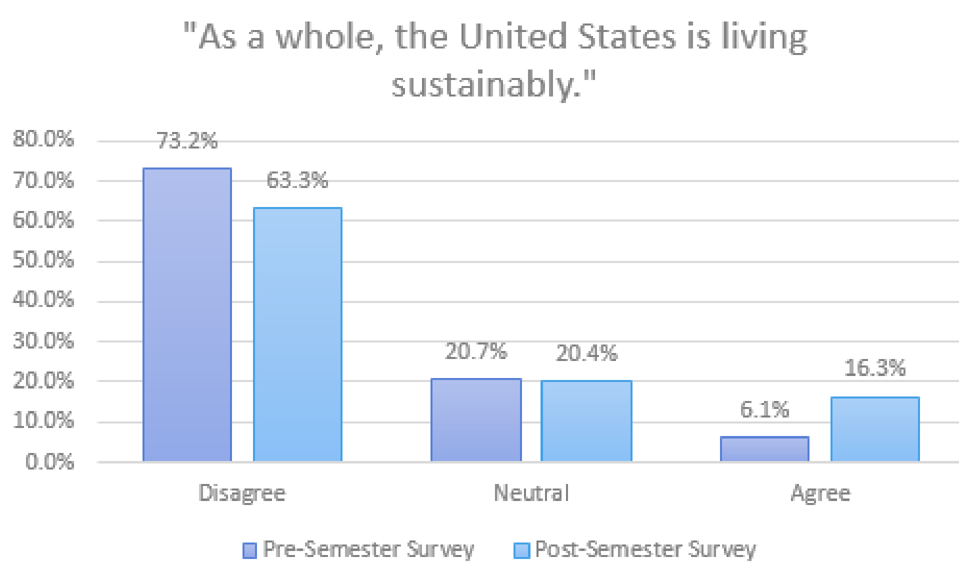

Figure 24: Percentage of Students in Combined Categories for Question Eight

disagreeing with the statement before the semester to students agreeing with the statement at the end of the semester. While this change is not statistically significant, it is surely interesting that more students agree at the end of the semester that they understand what sustainable living means in conjunction with more students agreeing at the end of the semester that the United States is living sustainably!

5 Improvements to be Made

Looking back on the experience allows room to see where improvements could have been made. If time had allowed, we should have designed the calculus questions before the semester began. It would provided more time for editing the problems and for researching richer discussion topics to enunciate the bridge between mathematics and sustainability. Creating the problems before the semester began also would have allowed us to better align the pre- and post-semester surveys. Since we went into the semester blind, we had to throw out many of the questions on the pre-semester survey, as we never got around to discussing certain sustainability topics during the semester. We might have been able to see more clearly a change in student action after the students had seen quantitatively the effects certain human actions have on our climate. Coming up with the calculus problems only a week before they were do also left us scrambling a bit, causing some of the problems to be much weaker than they could have been. In future experiments, it might be worth extending this project across two semesters, allowing one semester to come up with strong calculus problems and paired discussions, and the second semester to implement them. More time would also allow us to know exactly what we wanted students to get out of the experience going in and to create calculus questions that would bring up the sustainability topics we really wanted to touch on. In the future, we will also be sure to pair student answers on the pre-semester and post-semester surveys so that we can statistically analyze differences across the semester for specific students rather than analyzing general differences in the population of students who filled out the survey.

6 For Future Research

This project was just a first step towards quantitatively introducing sustainability topics to students whose fields do not revolve around sustainability. In the future, I would like to see mathematics educators from varying levels of mathematics extend the practice of introducing sustainability questions into their classrooms. This experience proved to me how difficult it is to create mathematics questions and how helpful it is to work together with someone on their construction. These understandings led me to create a blog for educators who might be interested in using our problems in their own classrooms and possibly in creating their own sustainability-related problems to share with other educators. This blog can be found at `https://miloshsr1.wixsite.com/calculus`. In general, I believe more research needs to be conducted on the effectiveness of sustainable education in mathematics. It would be interesting to gauge whether introducing sustainability-related mathematics questions improves students' understanding of certain sustainability issues or even has an effect on student actions. I also would be interested to see future research conducted on whether sustainable literacy is strengthened by the interpretation of graphs and data in mathematics courses, as well as whether improved sustainable literacy is correlated with increased student confidence in discussing sustainability issues with their peers. The bottom line is that the United States needs to get more of its public engaged with sustainability and climate change so that we can change our actions before it is too late to reverse the disastrous effects our actions can have. If mathematics education can positively effect public understanding of or engagement with sustainability, we need to capitalize upon the opportunity and begin to discuss sustainability in more of our math classes.

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